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U1S 1884 3043 C7A

(56) Documents cited
None

(58) Field of search
C7A

(54) **ERW-oil well pipe and process for producing same**

(57) An ERW oil-well pipe comprising in wt%:–

C – 0.22
Si – 0.50
Mn 1.0–2.0
Nb – 0.05
Fe balance

is strain-aged to exhibit low hardness and high yield strength, so that both sour-environment resistance and collapse resistance are improved as compared with quench and tempered pipes. The process involves inducing a 3% or more strain in the pipe and subsequently aging at 100-550°C for 30 seconds to 30 minutes.

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Fig.1

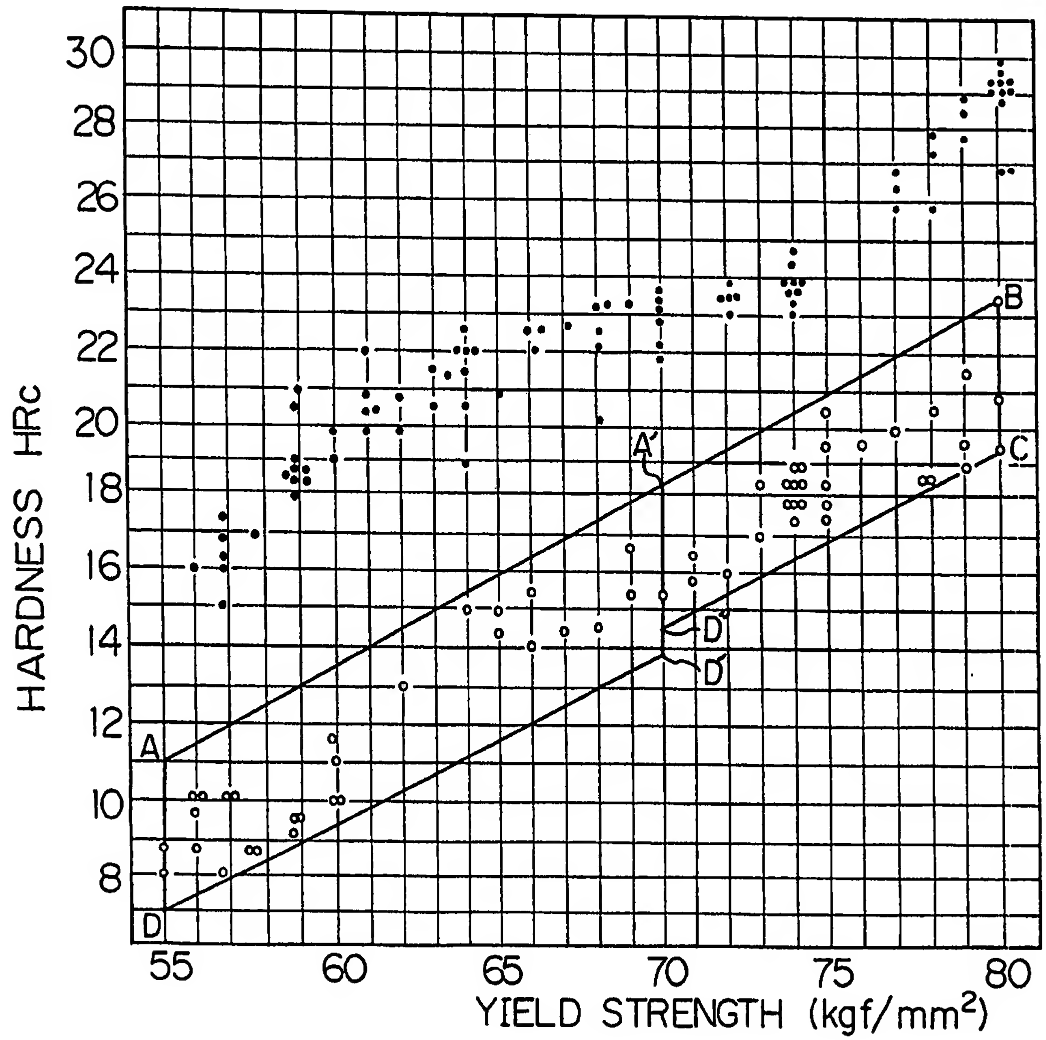

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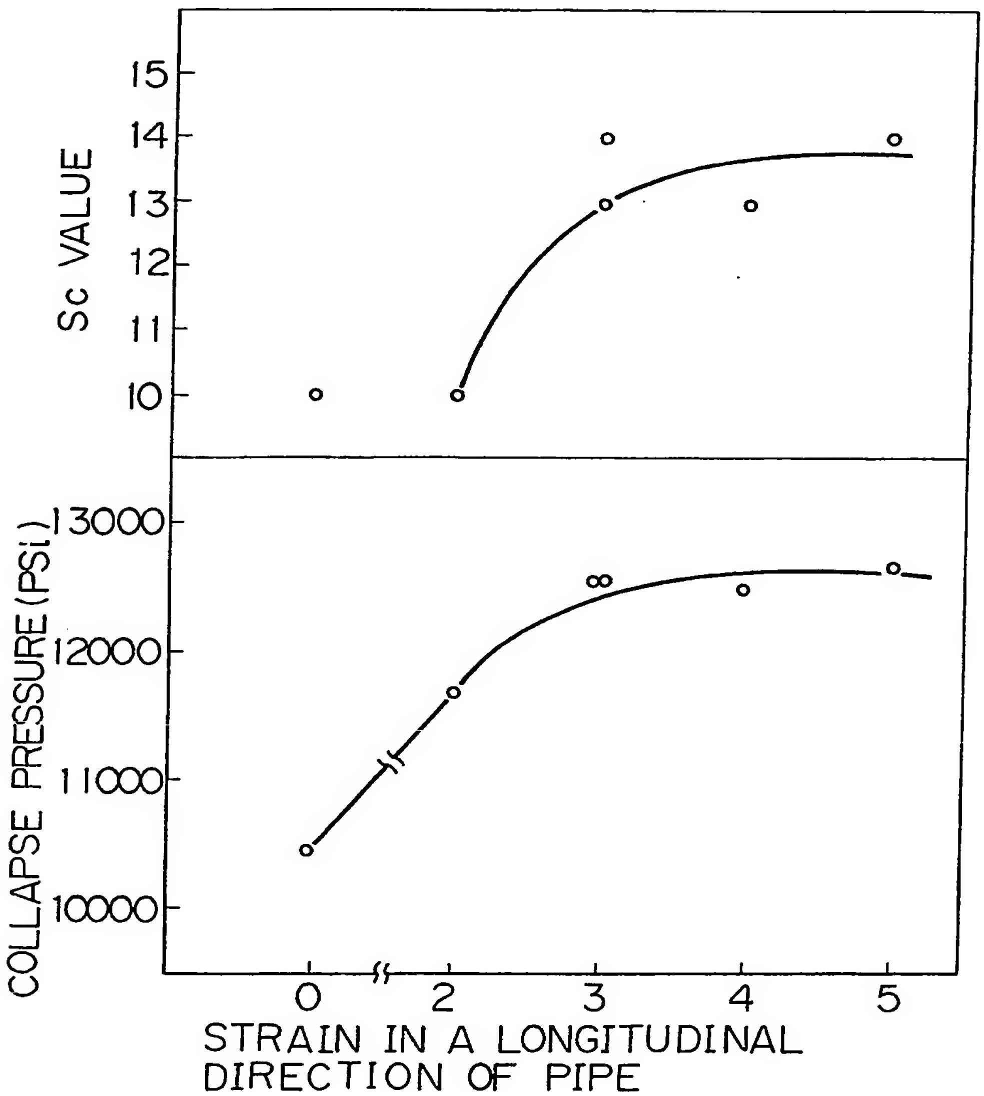
Fig. 2


15
14
13
12
11
10
Sc VALUE
13000
12000
11000
10000
COLLAPSE PRESSURE (PSi)
0
2
3
4
5
STRAIN IN A LONGITUDINAL DIRECTION OF PIPE

SPECIFICATION

ERW oil-well pipe and process for producing same

Background of the invention

1. *Field of the invention*

The present invention relates to an electric resistance welded (ERW) oil-well pipe having a low hardness and a high yield strength and to a process for producing the same.

2. *Description of the related art*

The demand for high sour-environment resistance and high collapse-strength type oil pipes has been increasing year by year along with the greater depths to which gas or oil wells have been drilled in recent years. All such deep oil wells are repeatedly subjected to sour gas environments. For example the hydrostatic pressure at an underground depth of 9000 m is approximately 900 atmospheres. According to the definition of the National Association of Chemical Engineers (NACE), an environment in which the hydrogen sulfide partial pressure is 0.05 psi or more is "sour". Thus, a hydrogen sulfide content of 5 ppm or more renders an environment sour, since the hydrogen sulfide partial pressure becomes 0.064 psi at a pressure of 900 atmospheres.

It is therefore indispensable for oil well pipes used in a deep well to have both excellent sour-environment resistance and collapse resistance.

The sour-environment resistance is enhanced by lessening the hardness and strength, while the collapse resistance is enhanced by enhancing the strength, particularly yield strength. Japanese Unexamined Patent Publication (Kokai) No. 53-138,916 discloses a method for producing ERW pipe utilizing quenching and tempering. In this method, an ERW pipe having welds is quenched from a temperature of from 800°C to 1000°C and tempered at a temperature of from 550°C to the A_{c1} point. It is, however, very difficult to obtain compatibly excellent sour-environment and crushing resistances by quenching and tempering. Also, deformation of pipes due to quenching and tempering must be rectified by straightening to improve the straightness and roundness. Deformation of pipes by quenching and tempering renders the production yield of pipes low.

Summary of the invention

It is an object of the present invention to provide an ERW oil-well pipe having both improved sour-environment resistance and collapse resistance, that is, a low hardness and high yield strength.

It is another object of the present invention to provide an ERW oil-well pipe having a high yield ratio and a satisfactorily high strength.

It is a further object of the present invention to provide a method for producing an ERW oil-well pipe by other than quenching and tempering.

An ERW oil-well pipe according to the present invention consists of 0.22% or less of C, 0.50% or less of Si, from 1.0 to 2.0% of Mn, 0.05% or less of Nb, and a balance of iron and unavoidable incidental elements including N. It is characterized by being placed in a strain-aged state to have the required hardness and yield strength.

The process for producing an ERW oil-well pipe according to the present invention includes the features of: carrying out hot-rolling at a low temperature to refine the crystal grains; after hot-rolling, rapidly cooling and coiling at a low temperature so as to retain stably the solute carbon and nitrogen in the matrix of steel; introducing, during the formation of a pipe from a sheet, plastic strain into the pipe material in an amount greater than the prior art, thereby increasing the number of dislocations; and fixing the solute carbon and nitrogen to the dislocations by heat treatment for a short period of time at low temperature.

The method for producing an ERW oil-well pipe according to the present invention is characterized by hot-rolling steel at a finishing temperature of from 740°C to 830°C, cooling the steel at an average cooling temperature of 15°C/sec or more down to the coiling temperature, coiling the steel at a temperature of 500°C or less, and; during the subsequent ERW pipe-forming process, applying a high reduction to cause 3% or more strain in a longitudinal direction. The pipe is subsequently heated to a temperature of from 100°C to 550°C for a period of from 30 seconds to 30 minutes.

Brief description of the drawings

Figure 1 is a graph showing the yield strength at the abscissa and the hardness (HRc) at the ordinate.

Figure 2 is a graph showing the relationshiop between the longitudinal strain of a pipe at the abscissa and the Sc value and collapse pressure at the ordinate.

Description of the preferred embodiments

The gist of the present invention lies on strain-aging of the ERW pipe material, in which the solute carbon and solute nitrogen retained in the ERW pipe material stick to and pin the dislocations which are introduced to the pipe material during the formation of the pipe.

The strain-aging provides compatibly excellent sour-environment resistance and collapse-resistance.

Strain-aging refers to changes in the mechanical properties of metals as a result of room or moderately elevated temperatures after plastic deformation. Strain-aging is usually avoided for steel, since it drastically deteriorates its mechanical properties, especially impact property. Strain-aging herein means that the solute carbon and solute nitrogen stick to and pin the dislocations induced in the steel due to plastic working, particularly cold plastic working. A strain-aged state herein means the state of steel of an ERW pipe in which the solute carbon and nitrogen stick to and pin the dislocations induced by plastic working.

The strain-aging and strain-aged state bring about outstanding changes in the relationship between the hardness and yield strength and in the relationship between the tensile and yield strength. The relationship between the tensile strength and yield strength is frequently expressed by the yield ratio, i.e., (the yield strength/tensile strength) × 100 (%). When the yield ratio is high, the sour-environment resistance and collapse resistance are compatible, since the collapse pressure is increased with an increase in the yield strength, and, further the sour-environment resistance is increased with a decrease in the tensile strength. Generally, the hardness and tensile strength vary in direct proportion to one another. Low hardness and thus low tensile strength provide a high sour resistance. The collapse pressure is not dependent on the tensile strength or hardness but depends greatly on the yield strength. Accordingly, a high yield ratio is indispensable for compatible sour resistance and collapse resistance. Desirably, the variation in the yield ratio of ERW oil-well pipes should be as small as possible.

Steel materials having a high yield ratio tend to feature lower ductility and toughness. Strain-aging, which is associated with the impairment of ductility, particularly impact strength, is usually not employed for improvement of steel properties.

The composition of an ERW oil-well pipe according to the present invention will now be described.

Carbon dissolved in the matrix of steel and sticked to the dislocations is used to provide both excellent sour-environment and crush resistances. An increase in the carbon content tends to reduce the yield ratio. Therefore, the highest carbon content is limited to 0.22%. Carbon effectively strengthens the steel when the carbon content is at least 0.08%.

Silicon also strengthens steel in a minor but effective content. When the silicon content exceeds 0.5%, however, yield ratio is lessened.

Manganese also strengthens the steel and enhances the yield ratio due to refinement of ferrite grains, at a content of at least 1.0%. The highest content of manganese should be 2.0% and is set so as not to impair the ductility and toughness.

Niobium refines the ferrite grains and enhances the yield ratio at a content of 0.05% at the highest. When the niobium content exceeds 0.05%, the dissolution of niobium in the matrix becomes difficult, and, thus, the ferrite grains cannot be refined by the precipitation of niobium.

Aluminum, vanadium, and titanium are optional alloying elements and strengthen the steel due to precipitation within the ferrite grains and/or refinement of the ferrite grains. These elements enhance the yield strength by precipitation hardening and/or refinement of the ferrite grains. The highest contents are 0.050% for aluminum, 0.050% for vanadium, and 0.040% for titanium. If these elements exceed the highest contents, they exceed the solubility limit.

The mechanical properties of the ERW oil-well pipe according to the present invention are shown in Figure 1. Referring to Figure 1, line AB refers to $y = 2x + 33$, line AD $y = 55$, line A'D' $y = 70$, line BC $y = 80$, line DD' $y = 2.14x + 40$, and line D"C $y = 2x + 41$. The ERW oil-well pipe according to the present invention, i.e., the strain-aged pipe, has a hardness and yield strength falling within the range defined by the points A, A', B, C, D", D', and D. The black dots above this range show the hardness and yield strength of conventional quenched and tempered ERW oil-well pipes. From the comparison of the mechanical properties of the quenched and tempered ERW oil-well pipes with the strain-aged pipe, it is apparent that a low hardness and a high yield strength, as well as a high yield ratio are provided by the present invention.

The ERW oil-well pipe having the hardness and the yield strength falling within the range defined by the points A, A', D', and D (hereinafter referred to as 80 ksi ERW oil-well pipe) and the ERW oil-well pipe having the hardness and the yield strength falling within the range defined by points A', B, C and D (hereinafter referred to as 95 ksi ERW oil-well pipe) are produced by adjusting the chemical composition and production conditions as follows.

80 ksi ERW oil-well pipe

The carbon content is from 0.08% to 0.19% and the average cooling rate at hot rolling is from 15 to 35°C/sec.

95 ksi ERW oil-well pipe

The carbon content is from 0.12% to 0.22% and the average cooling rate at hot rolling is from 20 to 45°C/sec.

The above described carbon content and the average cooling rate are adjusted depending upon the thickness and outer diameter of the ERW oil-well pipe. For producing the 80 ksi ERW oil-well pipe, the carbon content should be as low as possible in the range of from 0.08% to 0.12%. At least 0.12% of carbon is necessary for producing the 95 ksi ERW oil-well pipe. When the carbon content is determined, the average cooling rate at hot-rolling is then determined.

As is described above, strain-aging results in a high yield ratio, that is, a small difference between the tensile strength and yield strength. In other words, the tensile strength becomes relatively low. This is not advantageous from the viewpoint of strengthening steel. In the present invention, however, the carbon, silicon, and manganese in the content set as described above can satisfactorily strengthen the steel. In addition, the steel is also strengthened by the ferrite refinement. The ferrite grain size of the ERW oil-well pipe according to the present invention usually ranges from ASTM No. 13 to 14.

The production of an ERW oil-well pipe according to the present invention will now be described.

Slabs are produced by either the ingot-making and slabbing method or the continuous casting method. The continuous casting method is preferred from the viewpoint of fine-graining.

In hot-rolling of the slabs, the finishing temperature should be as low as possible, 830°C at the maximum, since the austenite grains are refined by low-temperature rolling, resulting in less probability an intermediate structure which reduces the yield ratio.

In addition, the low-temperature annealing allows generation of fine ferrite grains and rolled products with a high yield ratio. However, when the finishing temperature of hot-rolling is less than 740°C, the ferrite grains coarsen and thus the yield ratio is enhanced.

Cooling conditions after hot-rolling are important for minimizing the scatter of the strength and for retaining the solute carbon and solute nitrogen in the matrix of steel. The average cooling rate in a period between the finishing-rolling and coiling should be 15°C/sec or higher. Such an average cooling rate causes the pearlite transformation to complete at a given high rate while the steel strip travels on the run-out table. The completion of ferrite transformation at a given high rate on the run-out table results in minimum scatter of the strength. In addition, the cooling rate mentioned above results in a rapid austenite-ferrite transformation, so that the solute carbon and solute nitrogen of the austenite phase are retained in the ferrite. The average cooling rate should be generally high (low) for producing the 95 ksi (80 ksi) ERW oil-well pipe.

The coiling temperature should be 500°C or less to ensure stable retainment of the solute carbon and solute nitrogen in the ferrite phase. When the coiling temperature exceeds 500°C, carbon and nitrogen precipitate due to aging during the coiling and become inactive as to the strain-aging.

Now, the forming process is described. "Forming" process herein refers not only to forming or shaping the rolled product, i.e., a strip into a tubular form, but also to inducing strain in an amount appropriate for the strain-aging, which is carried out later than the forming process. The strain herein is the one in the longitudinal direction of an ERW oil-well pipe. Referring to Figure 2, the Sc value and the collapse pressure are enhanced by the longitudinal strain of the pipe. The Sc value expresses the durability-evaluation value in a "Shell Bent Beam Test". A longitudinal strain of a pipe of at least 3% is effective for inducing a number of dislocations to which the solute carbon and nitrogen stick, thereby improving the sour-environment resistance and collapse resistance.

The longitudinal strain is determined by the elongation percentage of the ERW oil-well pipe in the longitudinal direction, hereinafter referred to as the longitudinal elongation ε_3. The longitudinal elongation ε_3 is determined by the stri width W_0. The strip width W_0 for providing 3% or more of the longitudinal elongation ε_3 is calculated using the following formulas.

$$\varepsilon_3 = \left\{\frac{\varepsilon_1 - \varepsilon_2 + \varepsilon_1\varepsilon_2}{(1-\varepsilon_1)(1+\varepsilon_2)}\right\}(\times 100\,(\%)) \quad \ldots (1)$$

$$\varepsilon_2 = \left(\frac{3.97}{D} - \frac{0.0476}{t}\right)(\times 100\,(\%)) \quad \ldots (2)$$

$$\varepsilon_1 = \left\{\frac{W_0 - \pi(D-t)}{\pi(D-t)}\right\}(\times 100\,(\%)) \quad \ldots (3)$$

In the formulas, ε_1 is the size-reduction in the circular circumferential direction of the pipe, ε_2 is the thickness increase in the direction across the pipe wall, D is the diameter of pipe, t is the thickness of the pipe wall, and W_0 is the strip width. Formulas (1) and (3) are theoretical formulas, while formula (2) is an empirical formula including the inherent constants of an ERW mill.

The longitudinal strain is induced by working the strip by an ERW mill including breakdown rolls, sizing rolls, fin-pass rolls, and squeeze rolls.

As to the strain-aging process, the conditions of the strain-aging treatment vary depending upon the amount of solute carbon and nitrogen and the longitudinal elongation ε_3. A temperature of from 100°C to 550°C and time of from 30 seconds to 30 minutes are preferred. A low temperature and long time within the above ranges are preferred. Clearly, the conditions of the strain-aging treatment must be adjusted within the above temperature and time ranges, so that, depending upon the amount of solute carbon and nitrogen and the longitudinal elongation ε_3, the stress correlated with and generated by the strain is not appreciably reduced by the thermal activation. In addition, the conditions for the strain-aging treatment should also be

adjusted from an economic point of view and adjusted so as not to deteriorate the roundness and straightness of an ERW oil-well pipe.

The present invention is now explained by way of examples.

Example 1 (80 ksi ERW oil-well pipe)

ERW oil-well pipes 5 1/2" in outer diameter and 0.361" in wall thickness were produced under the conditions given in Table 1. The properties are also shown in Table 1. As apparent from Table 1, both the sour-environment resistance and collapse resistance of the pipes according to the present invention were excellent as compared with the comparative ERW oil-well pipes.

Table 1

Nos.	Chemical Composition (wt%) C	Si	Mn	Nb	V	Ti	Finishing Temperature (°C)	Average Cooling Rate (°C/sec)	Coiling Temperature (°C)	Average Strain in Longitudinal Direction of Pipe (%)	Heat Treatment Condition Temperature	Time	Collapse Strength (psi)	So Value (ksi)	Yield Strength (kgf/mm²)	Hardness (H_{RC})	Remarks
1	0.19	0.25	1.65	0.042	-	-	780	28	480	4	450°C	30 min	◎ 12600	◎ 13	69, 66	16.5, 15.5	Invention
2	"	"	"	"	-	-	"	28	"	3	500	10 min	◎ 12700	◎ 14	68, 69	14.5, 15.5	"
3	"	"	"	"	-	-	"	28	"	3	550	1 min	◎ 12600	◎ 15	66, 67	14.0, 14.5	"
4	0.18	0.19	1.6	0.038	-	-	790	30	500	5	450	10 min	◎ 12200	◎ 14	62, 65	13.0, 15.0	"
5	"	"	"	"	-	-	"	30	"	3	500	1 min	◎ 12000	◎ 15	65, 64	14.5, 15.0	"
6	"	"	"	"	-	-	"	30	"	3	550	30 sec	◎ 12200	◎ 15	60, 60	11.0, 11.5	"
7	0.15	0.17	1.7	0.020	0.040	0.015	800	33	490	4	450	10 min	◎ 12300	◎ 15	59, 58	9.5, 8.5	"
8	"	"	"	"	"	"	"	33	"	4	500	1 min	◎ 12200	◎ 15	60, 61	10.0, 10.5	"
9	"	"	"	"	"	"	"	33	"	4	550	30 sec	◎ 12500	◎ 15	61, 60	10.0, 10.0	"
10	0.12	0.20	1.7	0.042	-	0.015	780	29	480	5	450	30 min	◎ 12200	◎ 15	57, 56	10.0, 10.0	"
11	"	"	"	"	-	"	"	29	"	5	500	10 min	◎ 12200	◎ 16	59, 59	9.5, 9.0	"
12	"	"	"	"	-	"	"	29	"	5	550	30 sec	◎ 12100	◎ 16	58, 57	8.5, 8.0	"
13	"	"	"	"	-	"	"	27	500	5	450	1 min	◎ 12200	◎ 15	56, 55	8.5, 8.0	"
14	"	"	"	"	-	"	"	27	"	5	500	30 sec	◎ 12300	◎ 17	57, 56	10.0, 9.5	"
15	"	"	"	"	-	"	"	27	"	5	550	30 sec	◎ 12000	◎ 17	55, 56	8.5, 10.0	"

Table 1 (Continued)

Nos.	Chemical Composition (wt%) C	Si	Mn	Nb	V	Ti	Finishing Temperature (°C)	Average Cooling Rate (°C/sec)	Coiling Temperature (°C)	Average Strain in Longitudinal Direction of Pipe (%)	Heat Treatment Condition Temperature	Time	Collapse Strength (psi)	Sc Value* (ksi)	Yield Strength (kgf/mm²)	Hardness (H_{RC})	Remarks
16	0.08	0.26	1.84	0.046	-	0.017	800	35	480	3	500	1 min	◎ 12200	@ 18	60, 61	13.0, 13.0	Comparative
17	"	"	"	"	-	"	800	15	650	5	450	60 min	x 10800	o 13	49, 50	8.5, 7.0	"
18	"	"	"	"	-	"	780	29	480	2	450	30 min	x 11000	x 11	55, 56	8.5, 8.5	"
19	"	"	"	"	-	"	"	"	"	4	no	no	x 10400	x 8	52, 56	8.5, 10.0	"
20	"	"	"	"	-	"	"	"	"	4	600	1 min	x 9800	o 12	48, 49	7.0, 7.5	"
21	"	"	"	"	-	"	"	"	"	4	600	1 min	x 9900	x 10	49, 49	8.0, 8.0	"

Note: *-Sc Value is an index for evaluation of the sour-environment resistance and is given from the results of "Shell Bent-Beam Test".

Example 2 (95 ksi ERW oil-well pipe)

ERW oil-well pipes 5-1/2" outer diameter and 0.361" in wall thickness were produced under the conditions given in Table 2. The properties are all also shown in Table 2. As apparent from Table 2, both the sour-environment resistance and collapse resistance of the pipes according to the present invention were excellent as compared with the comparative ERW oil-well pipes.

Table 2

Nos.	Chemical Composition (wt%) C	Si	Mn	Nb	V	Ti	Finishing Temper-ature (°C)	Average Cooling Rate (°C/sec)	Coiling Temper-ature (°C)	Average Strain in Longi-tudinal Direction of Pipe (%)	Heat Treatment Condition Temper-ature	Time	Collapse Strength (psi)	Sc Value (ksi)	Yield Strength (kgf/mm^2)	Hardness (H_{RC})	Remarks
1	0.19	0.25	1.65	0.042	–	–	780	27	500	5	450°C	10 min	◎ 13600	◎ 15	70, 72	15.5, 16.0	Invention
2	"	"	"	"	–	–	"	27	"	5	500	1 min	◎ 13400	◎ 14	71, 71	16.0, 16.0	"
3	"	"	"	"	–	–	"	27	"	5	550	30 sec	◎ 13700	◎ 13	73, 74	18.5, 18.5	"
4	"	"	"	"	–	–	"	33	450	4	450	10 min	◎ 13300	◎ 13	74, 74	19.0, 18.0	"
5	"	"	"	"	–	–	"	33	"	4	500	1 min	◎ 13900	◎ 14	74, 75	18.0, 18.5	"
6	"	"	"	"	–	–	"	33	"	4	550	30 sec	◎ 1300	◎ 14	75, 74	18.0, 18.0	"
7	0.21	0.19	1.70	0.041	–	0.015	800	32	490	4	450	1 min	◎ 13900	◎ 14	78, 80	18.5, 19.5	"
8	"	"	"	"	"	"	"	32	"	4	500	1 min	◎ 13200	◎ 14	75, 75	17.5, 20.5	"
9	"	"	"	"	"	"	"	32	"	4	550	1 min	◎ 13900	◎ 14	76, 77	19.5, 20.0	"
10	"	"	"	"	–	"	"	34	470	4	450	30 min	◎ 13800	◎ 13	80, 79	21.0, 21.5	"
11	"	"	"	"	–	"	"	34	"	4	500	1 min	◎ 13900	◎ 13	80, 79	23.5, 19.0	"
12	"	"	"	"	–	"	"	34	"	4	550	1 min	◎ 14000	◎ 13	78, 79	22.5, 19.5	"
13	0.17	0.25	1.80	0.040	0.025	0.015	770	32	480	3	450	30 min	◎ 13000	◎ 13	74, 74	18.5, 18.5	"
14	"	"	"	"	"	"	"	32	"	3	500	10 min	◎ 13100	◎ 13	74, 75	19.0, 19.5	"
15	"	"	"	"	"	"	"	32	"	3	550	30 sec	◎ 13100	◎ 13	74, 73	17.5, 17.0	"
16	0.17	0.25	1.80	0.040	0.025	0.015	900	40	480	3	450	60 min	x 11900	x 8	69, 68	25.0, 26.0	Comparative
17	"	"	"	"	"	"	800	14	650	3	450	60 min	x 10800	Δ 12	65, 64	17.0, 18.0	"
18	"	"	"	"	"	"	770	32	480	2	450	1 min	x 12000	x 10	72, 73	18.5, 19.0	"
19	"	"	"	"	"	"	770	32	480	3	600	30 sec	x 11300	Δ 12	68, 67	18.0, 18.5	"
20	"	"	"	"	"	"	770	32	480	3	no	no	x 11700	x 11	67, 66	19.0, 18.5	"

CLAIMS

1. An ERW oil-well pipe consisting of 0.22% or less of C, 0.50% or less of Si, from 1.0 to 2.0% of Mn, 0.05% or less of Nb, and the balance of iron and unavoidable incidental elements including N, characterized by being in a strain-aged state and having a hardness and yield strength falling within the range defined by points A, A', B, C, D", D', and D shown in the attached Figure 1.

2. An ERW oil-well pipe according to claim 1, characterized by containing at least one member selected from the group consisting of aluminum in an amount of 0.050% or less, vanadium in an amount of 0.050% or less, and titanium in an amount of 0.040% or less.

3. An ERW oil-well pipe according to claim 1 or 2, characterized by having the hardness and yield strength falling within the range defined by the points A, A', D', D.

4. An ERW oil-well pipe according to claim 3, wherein the carbon content is 0.19% or less.

5. An ERW oil-well pipe according to claim 1 or 2, characterized by having the hardness and yield strength falling within the points A', B, C, and D".

6. An ERW oil-well pipe according to claim 5 wherein the carbon content is from 0.12% to 0.22%.

7. A process for producing an ERW oil-pipe according to claim 1 or 2, characterized by hot-rolling steel at a finishing temperature of from 740°C to 830°C, cooling the steel at an average cooling temperature of 15°C/sec or more down to the coiling temperature, coiling the steel at a temperature of 500°C or less, and, during a subsequent forming process of a pipe, inducing 3% or more strain in a longitudinal direction of the pipe during formation of the pipe and subsequently heating the pipe to a temperature of from 100°C to 550°C for a period of from 30 seconds to 30 minutes.

8. A process according to claim 7, wherein the ERW oil-well pipe has hardness and yield strength falling within the range defined by the points A, A', D', D, and, a carbon content of from 0.08% to 0.19%, and the average cooling rate is from 15 to 35°C/sec.

9. A process according to claim 7, wherein the ERW oil-well pipe has a hardness and yield strength falling within the points A', B, C, and D", and a carbon content from 0.12% to 0.22%, and the average cooling rate is from 25 to 45°C/sec.

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